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Research on Chemical Control Technology of Sand Production in Pai 10 West Oil Well

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Abstract: Pai 10 West Oilfield, located in the west of Chunguang Oilfield, is a typical medium and high permeability thin oil lithologic reservoir, with serious sand production problems, and the traditional mechanical sand control technology has a short validity period, which cannot meet the long-term development needs of this block. In order to solve this problem, a high-strength self-emulsifying sand fixing agent system (HCS) based on epoxy resin was developed in this paper, and its performance under complex geological conditions was verified by experiments. In the experiment, the performance of the sand fixing agent was comprehensively evaluated by sand particle sieve analysis, sand filter performance test, bottomhole environment simulation, anti-aging and anti-erosion experiments. The results show that the sand fixing agent can effectively form a uniform cladding layer, significantly improve the consolidation strength of sand particles, and maintain excellent compressive strength and permeability in high temperature, high pressure and complex downhole environment, with excellent erosion resistance. In addition, the sand fixing agent exhibits excellent anti-aging ability and can maintain high strength and stability over a long period of time. The research results of this paper provide an innovative technical scheme for efficient sand control in Pai 10 West Block, and also provide a reference for the sand production problem of similar high-permeability reservoirs.

Keywords: Oil Field; Sand Production; Chemical Sand Control; Epoxy Resin; Sand Fixing Agent.

1. Introduction

Pai 10 West Block is located in the west of Chunguang Oilfield, which is a typical medium and high permeability thin oil lithologic reservoir(King et al., 2018). The main development strata of the block are the Shawan Formation, which is divided into No. 1 and No. 2 Sand Formations. Because the cementation type of the reservoir is mainly pore cementation, the cementation is mainly argillaceous, the heterogeneous components are mainly clay, and the formation structure is relatively loose, so the sand problem is very easy to occur in the mining process(Valenti, 1993).Sand production not only causes damage to wellbore equipment, but also leads to lower oil production, higher production costs, and may even lead to more serious safety incidents, which are common and difficult to control, especially in loose sandstone reservoirs(Tamis et al., 2012). Traditional mechanical sand control methods, such as the use of suspended sand filter pipes and circulating filling, can alleviate the sand production problem to a certain extent, but their validity period is usually short, and they are easy to fail in high-permeability reservoirs(Zhan et al., 2019). The sand production problem in the 10th West Block is particularly serious, and the validity period of the suspended sand filter pipe and circulating filling sand control technology used in the early stage is only 154 days, which cannot meet the requirements of long-term and efficient development(Bik-Małodzińska et al., 2023).

With the deepening of oilfield development, the problem of sand production is due to the migration of sand grains themselves, and is also affected by many factors such as formation pressure, fluid properties, and injection-production dynamics. In addition, differences in reservoir conditions, changes in the downhole environment, and long-term exploitation of wells can exacerbate the degree of sand production(Deng et al., 2022a). Therefore, in order to improve the efficiency of oilfield development in Pai 10 West Block, it is urgent to develop an efficient and long-term chemical sand control technology that adapts to the specific conditions of the block.

In recent years, chemical sand control technology has been used as an effective means of sand control, and the chemical sand control agent reacts with the surface of the sand particles to form a solid covering layer, so as to prevent the migration of sand particles into the wellbore. Compared with mechanical sand control technology, chemical sand control technology has the advantages of simple process, strong adaptability and long-lasting sand control effect, and is especially suitable for reservoirs with high permeability and complex geological conditions.

In this study, in order to solve the problem of sand production in the 10 West Block, through the sieve analysis of formation sand, a high-strength self-emulsifying sand fixing agent system (HCS) based on epoxy resin was developed and optimized for this block, and the sand fixing agent can maintain high strength and permeability in the complex downhole environment by grafting the active group through epoxy resin. The research results not only provide theoretical support and technical support for the efficient development of Pai 10 West Block, but also provide an important reference for sand control work in similar oilfields

2. Experimental Methods

2.1. The Main Experimental Material

n-butanol, ethylene glycol monobutyl ether, BPO, monomer 3 (methyl methacrylate), sodium bicarbonate were purchased from Sinopharm Chemical Reagent Co., Ltd.; Monomer 1 (3,4-dihydroxyacrylic acid) was purchased from Sarn Chemical Technology (Shanghai) Co., Ltd.; Monomer 2 (N-vinylpyrrolidone) was purchased from Aladdin Reagent (Shanghai) Co., Ltd.; Epoxy resin E-44 was purchased from Feicheng Deyuan Chemical Co., Ltd.; The coupling agent was purchased from Jinan Jinhui Chemical Co., Ltd.; The curing agent and softener were purchased from the Pujiang

Fine Chemical Plant in Sichuan. The above reagents are analytically pure.

2.2. Main Experimental Instruments

DF-101Z Collector Thermostatic Heating Magnetic Stirrer; 98-1-B Constant Temperature Electronic Thermostat Electric Heating Jacket; SYP Smart Glass Thermostatic Water Bath; DGG-9070AD Electric Constant Temperature Blower Drying Oven; Core gripper, glass measuring cylinder, vernier caliper, stopwatch, thermostatic water bath, universal material press, balance scale, reaction mold (glass tube)

2.3. Synthesis of Activated Sand Fixing Agent

a. Add a certain ratio of E-44, monomer 1 and monomer 2 to a 150ml four-mouth flask;

b. According to the required concentration, add a certain proportion (3:1) of n-butanol and ethylene glycol monobutyl ether, and put the four flasks into the oil bath to heat the constant temperature;

c. Nitrogen is introduced to prevent the oxidation of monomers in the system;

d. Add a certain amount of solid initiator benzoyl peroxide to initiate its reaction.

After the reaction for a period of time, add a certain amount of sodium bicarbonate to adjust the PH≈7 value, add 150ml of water and stir until it is evenly dispersed and emulsion-like.

f. The polymerization products precipitated by demulsification are dried, washed, extracted by Soxhlet, and dried in a vacuum drying oven for 1~2 days, and then put into a bag for later use.

2.4. Experimental Methods

Sand filter performance test: put the consolidated rock sample into the core gripper, put a Φ25mm×25mm steel pipe in front of the core, load the experimental sand into the steel pipe, and add confining pressure(Yi, 2008). Replace with clean water, the flow rate is 1ml/min, the injection volume is 250ml, and the filtrate is analyzed for sand content. Subsequently, crude oil was used for displacement at a flow rate of 0.5ml/min and an injection volume of 250ml, and the filtrate was analyzed for sand content.

Bottom well environment experiment: the oil sand with sewage is loaded into a Φ25mm*25mm sand filling pipe, and the two ends are compacted with perforated rubber plugs(Zhang et al., 2021). A 2% BS-12 surfactant solution of 2-3PV was injected to clean the oil sands. The glass tube is then injected with a 1PV formulated sand fixing agent, followed by 1PV of diesel fuel as a replacement reaming solution. It was cured in a constant temperature water bath at 60°C for 72 hours to determine the compressive strength and permeability of the consolidated body(Wilson et al., 2014). Repeat the steps above several times.

Continuous erosion experiment: The consolidated body for sand washing was baked at 60 °C for 24 h according to the basic formula to make the specifications of Φ2.5 cm×5 cm. The scouring flow rate was set at 30 mL.min-1, the time was 7 days, the water pressure was kept at about 2 MPa during the sand flushing process, the water sample at the end of the consolidated body was collected, the wet sand on the filter paper was dried and weighed after filtering, and the sand yield was used as the evaluation standard(Tamis et al., 2012).

$$\text{Sand production rate} = \frac{Sand\ dry\ weight}{Dry\ weight\ of\ consolidated\ body\ before\ sand\ washing} \times 100\%$$

Anti-aging experiment: put the consolidated core into the water bath for 72 hours after the solidification reaction was put into clean water, put it in a constant temperature water bath for aging experiment, and take out part of the core every five days to measure its compressive strength and permeability (Põllumaa et al., 2001).

3. Results and Discussion

3.1. Formation Sand Screening and Particle Size Analysis

Table 1. Screening results of formation sand particle size of three oil wells in the west of Pai 10

Particle size distribution (Mass Percentage)	Su-1-7 (No sand)	Su-1 - oblique 213 (Sand production is slight)	Su-1 - oblique 131 (Severe sand production)
(>850um)	/	4.50%	/
(850-710um)	/	5.90%	/
(710-600um)	/	8.70%	/
(600-500um)	2.50%	10.10%	2.00%
(500-425um)	5.60%	11.50%	3.50%
(425-355um)	17.40%	11.50%	4.30%
(355-300um)	27.90%	11.10%	8.00%
(300-250um)	25.60%	10.90%	13.50%
(250-212um)	12.50%	7.60%	12.90%
(212-180um)	5.80%	7.60%	16.60%
(180-150um)	1.60%	5.50%	15.70%
(150-125um)	0.70%	2.60%	8.40%
(125-106um)	0.20%	1.00%	4.90%
(106-75um)	0.10%	1.00%	6.10%
≤75um	0.10%	0.50%	4.20%

In order to accurately grasp the characteristics of formation sanding, this paper carried out detailed screening and particle size analysis of formation sand samples from three oil wells in Pai 10 West Block. In the experiment, the distribution of formation sand in different particle size ranges was determined by vibrating sieve instrument, as shown in Table 1,The median grain size D50 of Well Su 1-7 was 0.32mm, and the silt and fine sand content was 2.7%(Nutting, 1925). The median grain size D50 of Well Su 1-Dip 213 was 0.35mm, and the silt and fine sand content was 10.6%. The median grain size of Well Su 131 was 0.18mm, and the silt and fine sand content was 39.3%(Nayberg, 1987). Combined with the actual sand production of the three oil wells, it can be seen that with the increase of silt and fine sand (sand particles with small particle size), the sand production problem of oil wells gradually intensifies. This indicates that the migration of silt and fine sand is one of the key factors causing the sand problem, especially the blockage of the backfill layer and the deposition of sand particles in the wellbore(Herzik, 1992). Oil wells with severe sand production are usually accompanied by higher silt and fine sand content and lower median sand particle size, indicating that fine sand particles have stronger fluidity and are more likely to enter the wellbore with oil flow(Gómez-Mellado et al., 2020).

3.2. Performance Evaluation of High-Strength Chemical Sand Control and Sand Fixing Agents

1. Scanning electron microscope test of consolidated sand core

Emission scanning electron microscopy was used to characterize the sand core after sand fixation, and the results are shown in Figure 1, which shows that the sand fixing agent forms a uniform coating layer on the surface of the sand particles(Engelhardt, 1999). Under the action of coupling agent and curing agent, the active sand fixing agent with cross-linking reaction forms a cross-linked network structure, and the sand particles are bridged and cemented with each other, and the porous structure between the sand particles ensures the permeability of the consolidated body to a certain extent(Deng et al., 2022b).

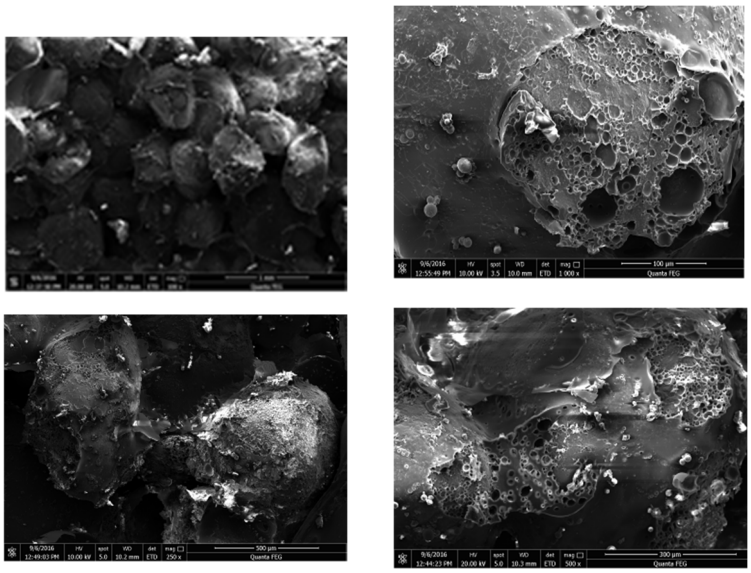


Fig 1. SEM of bonded section

2. The influence of colloidal particle size on consolidation strength

As can be seen from Table 2, the consolidation strength of the activated sand fixing agent reaches 7.76 MPa for the sand particles with small particle size (0.079 mm), while that of XD-3 sand fixing agent is only 6.34 MPa(Chernova et al., 2020). With the increase of formation sand particle size, the consolidation strength of XD-3 sands fixing agent and activated sand fixing agent decreased gradually, but under the larger particle size (0.187 mm), the consolidation strength of activated sand fixing agent still maintained 5.82 MPa, which was significantly better than that of XD-3 sand fixing agent of 5.16 MPa. The results show that the chemical structure of the activated sand fixing agent has stronger cementation ability, which can effectively cope with particle size changes, ensure high consolidation strength, and is suitable for sandstone environment with multiple particle sizes.

Table 2. Effect of particle size on sand fixation strength

type	Consolidation strength/MPa							
Particle size(mm)	0.079	0.093	0.106	0.121	0.135	0.148	0.169	0.187
XD-3 class	6.34	6.28	6.12	5.79	5.69	5.53	5.35	5.16
Activated sand fixation	7.76	7.12	6.95	6.89	6.53	6.12	5.89	5.82

3. Sand filter performance

Sand filter performance is an important criterion and assessment index to evaluate whether the sand control agent can be applied to the site, so the sand filter performance of the sand fixing agent is evaluated through the sand filter performance experiment.

It can be found from Table 3 that no sand particles were found in the filtrate after flooding with clean water and then with crude oil, indicating that the active sand fixing agent showed a good sand fixation effect. This means that the sand fixing system can effectively prevent the migration of sand particles in the wellbore, avoiding equipment wear and loss of production efficiency.

Table 3. Experimental results of filter sand performance

Protocol	Dosage of sand fixing agent (PV)	Injection speed (ml/min)	Injection volume (ml)	Out of the sand circumstance
Replacement with clear water	1	1	250	not
Crude oil displacement	1	0.5	250	not

4. Performance Evaluation in the Bottom Hole Environment

With the deepening of the development of old oil wells, the formation and oil well sand production are becoming more and more complex and diversified, and the temperature, pH, salinity and argillaceous content of different oil layers are different in oil well operation, which will reduce the effect of sand fixing agent. Considering the complex factors of the downhole environment, simulation experiments were carried out on the downhole environment to verify its sand fixation effect in the complex environment.

1) Effect of Crude Oil Adhesion on the Consolidation Strength of Sand Fixing Agent

The effect of crude oil content on the compressive strength of the consolidated body is shown in Fig. 2 and Fig. 3. With the increase of the content of crude oil and sewage adhered to the surface of formation sand, the adsorption effect of ordinary sand fixing agents such as ST-1 and XD-3 deteriorated, because the crude oil adheres to the surface of the sand particles, which hinders the consolidation of resin on the surface of the sand particles, resulting in poor performance of the consolidated body and a significant decrease in compressive strength. The crude oil content exceeds 10%, and the consolidation effect of sand fixing agents ST-1 and XD-3 has not reached the requirement of 4MPa. However, the activated sand fixing agent is very little affected by the crude oil content, and the consolidation strength remains basically unchanged, which is due to the fact that the activated sand fixing agent has the function of washing oil, which can effectively reduce the oil adhesion on the surface of the sand particles and maintain high compressive strength.

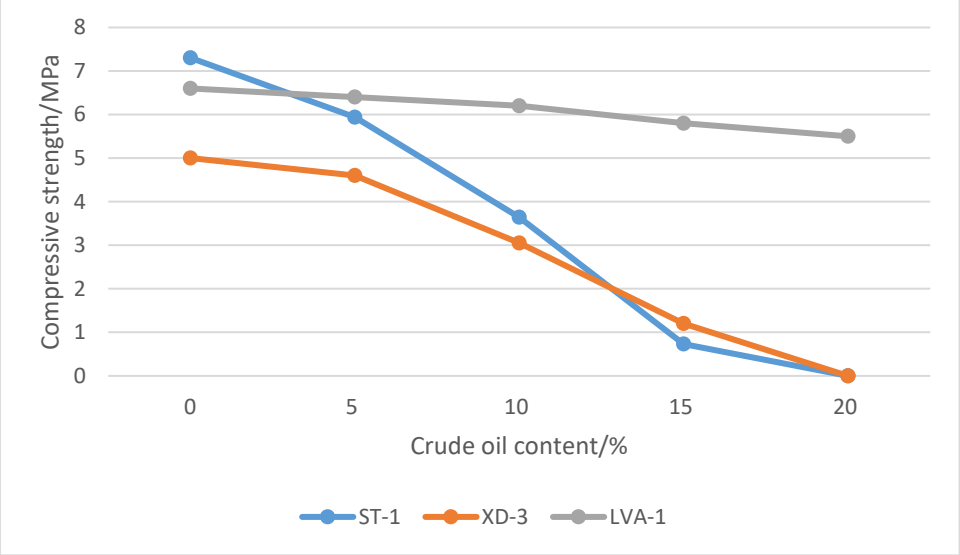


Fig 2. Effect of crude oil content on the compressive strength of consolidated bodies



Fig 3. contains the state of sand grains

2) Effect of Argillaceous Content on the Consolidation Strength of Sand Fixing Agent

As can be seen from Figure 4, the higher the argillaceous content, the lower the consolidation strength of the

consolidated body. This is due to the formation of a weak chemical bond between the argillaceous and the sand fixing agent, which is not conducive to the formation of -Si-O-. It affects the cementing effect of the sand fixing agent. However, the compressive strength of the activated sand fixer decreases less, showing stronger adaptability and anti-pollution ability.

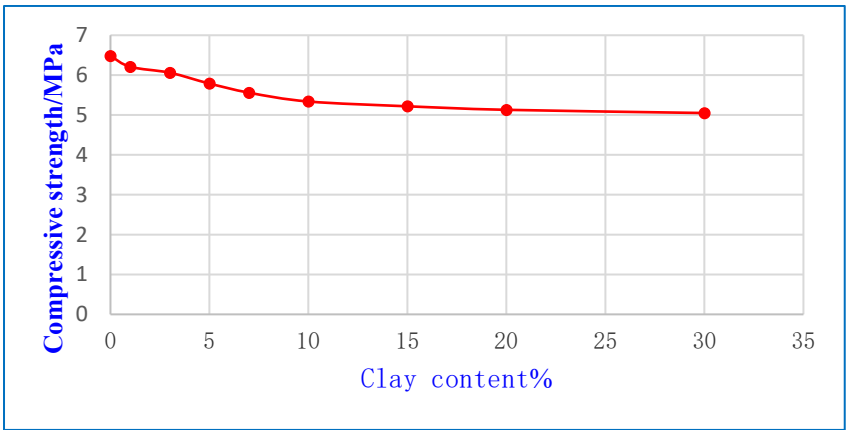


Fig 4. Effect of argillaceous content of different sand fixing agents on compressive strength

5. Evaluation of continuous erosion performance

The large displacement water sand flushing was used to simulate the sand production of loose sand consolidation under the condition of formation fluid flow. After 7 days of long-term scouring with large displacement, the appearance of the consolidated body remained good, the dry weight of the sand-containing water at the end of the consolidated body sample was 0.01 g, the dry weight of the consolidated body before sand washing was 36.32 g, and the sand yield of the consolidated body was only 0.0275%, indicating that the modified epoxy resin sand fixing system could still maintain its structural integrity under high flow rate and high pressure, and showed excellent anti-erosion performance.

6. Anti-aging experiment

After the sand control operation, the sand control method used is required to effectively prevent the sand particles from moving to the wellbore, and the sand control method used is required to have a long validity period, so as to avoid frequent workover operations. If the sand control method is valid for a period of time, it not only increases the cost, but also greatly affects the normal production of the oil well. For chemical sand fixing agents, in order to maintain their long validity period, it is necessary to use sand fixing agents to maintain good strength and permeability for a long time in high temperature and high humidity formation environment, which requires chemical sand fixing agents to have strong anti-aging properties.

In order to verify that the prepared sand fixing agent has a long expiration date, the consolidated body is put into a water bath at 60 °C for 72 hours after the curing reaction, the obtained consolidated core is put into clean water, put into a constant temperature water bath for aging experiment, and part of the core is taken out every five days to measure its compressive strength and permeability. The measurement results are shown in Table 4.

Table 4. Effect of aging time on compressive strength and permeability

Aging time/d	Compressive strength/MPa	Permeability/um2
5	9.1	6.6
10	8.4	7.1
15	8	7.9
20	7.1	8.3
25	6.9	8.9

At the beginning of aging (the first 5 days), the compressive strength of the sand fixing agent is 9.1 MPa and the permeability is 6.6 μm², showing high initial strength and can effectively maintain the permeability of the formation. This indicates that the newly synthesized sand fixing agent has strong cementing ability in the short term. With the increase of aging time, the compressive strength gradually decreases. By day 10, the compressive strength decreased to 8.4 MPa and further to 8.0 MPa at day 15. The permeability gradually increased, to 7.1 μm² on day 10 and further to 7.9 μm² at day 15. This suggests that the pore structure of the sand fixer in the downhole environment may have undergone some changes over time, resulting in a slight increase in permeability. At 20 days of aging, the compressive strength decreased significantly to 7.1 MPa, and finally at 25 days, the compressive strength remained at 6.9 MPa. This indicates that the compressive performance of the sand fixing agent gradually weakens during the long-term aging process, but still maintains a certain strength range. The permeability increased to 8.3 μm² and 8.9 μm², respectively, indicating that the mesh structure of the fixing agent may have loosened, resulting in a continued increase in permeability.

4. Conclusion

In this paper, a high-strength self-emulsifying sand fixing agent system (HCS) based on epoxy resin was developed and

studied in order to solve the sand production problem in Pai10xi Oilfield, and the performance of the system was evaluated in detail through a series of experiments, and the main conclusions are as follows:

1. The sand fixing agent has superior performance, adapts to a variety of formation conditions, and

shows excellent consolidation strength under different particle size conditions of formation sand, especially in reservoirs with high permeability and high silt and fine sand content, showing significant sand fixation effect. The SEM characterization results showed that the sand fixing agent could form a uniform and dense coating layer on the surface of the sand particles, which enhanced the cementation force between the sand particles.

2. The sand filter performance is good, and it is found

that the sand fixing agent does not produce sand in the clear water and crude oil displacement experiments, indicating that the sand fixing agent can effectively prevent the migration of sand particles, keep the wellbore clean, and improve the stability of oil well production in the complex environment of the bottom hole.

3. The anti-aging and anti-erosion properties are outstanding, ensuring long-term stability

and sand fixing under long-term aging conditions (high temperature and high humidity environment), its compressive strength only decreases slightly, and remains at 6.9 MPa after 25 days, showing strong anti-aging ability. At the same time, the results of the 7-day high-pressure scouring test showed that the sand yield of the sand fixing agent was extremely low, the anti-erosion performance was excellent, and the structural integrity of the wellbore could be maintained in the long-term production process.

4. Adaptable to crude oil and argillaceous

sand fixing agents have low sensitivity to crude oil and argillaceous content. Even in the downhole environment with high crude oil and argillaceous conditions, the sand fixing agent still maintains high compressive strength, indicating that it has a wide range of applicability in complex downhole environments.

In summary, the epoxy resin-based sand fixing agent system developed in this paper provides an effective solution for long-term sand control in Pai 10 West Block and similar high-permeability oilfields. This technology has the advantages of simple process, moderate cost and stable effect, and has a wide range of popularization and application potential, providing solid technical support for future oilfield development.

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